Army Research Laboratory

The Mechanical Response of Virgin and Aged RDX/CL20/BAMO/AMMO-Based High-Energy Gun Propellants

by Michael G. Leadore

ARL-TR-2603 September 2001

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5069

ARL-TR-2603 **September 2001**

The Mechanical Response of Virgin and Aged RDX/CL20/BAMO/AMMO-Based High-Energy Gun Propellants

Michael G. Leadore
Weapons and Materials Research Directorate, ARL

Abstract

The subject of this report is the material test systems servohydraulic tester high-rate mechanical response of TSE-015-019 sample nos. 5 and 6 RDX/CL20/BAMO/AMMO-layered gun propellants that were aged for more than 2 years. The Thiokol manufactured materials identified by lot TSE-015-019 were initially tested (virgin lot) in September 1997 and January 2000. Sample no. 4 was a candidate propellant for the M829E3 120-mm tank gun round of test sets 28–34/FY00.

Table of Contents

INTENTIONALLY LEFT BLANK.

List of Figures

List of Tables

INTENTIONALLY LEFT BLANK.

1. Background

The U.S. Army Research Laboratory (ARL) received two lots of TSE-015-019 sample nos. 5 and 6 RDX/CL20/BAMO/AMMO-layered next generation high-energy 120-mm gun (Figure 1) propellants that were manufactured at Thiokol Propulsion Corporation, Elkton, MD. The materials were made in a mixer and extruded thermally into sheets. The sheet material had a thickness of ~2.80 mm. The sheet was cut into 25.40-mm × 25.40-mm squares, and several squares from the lot of the experimental gun propellant were shipped to Dr. Robert Lieb of ARL. The virgin material was first tested during September 1997, and aged sample no. 4 was tested during January 2000. The results are contained in Table 1. Subject material sample nos. 5 and 6, plus 2-year aged material, were last tested for high-rate compressive mechanical response evaluation in September 2000.

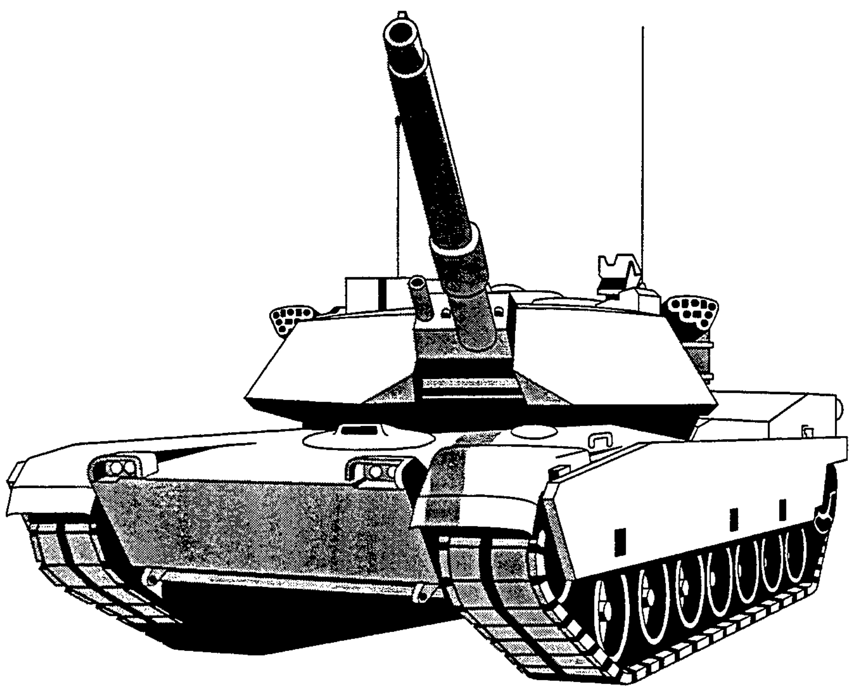

Figure 1. M1 Abrams With 120-mm Gun.

Table 1. **Mechanical Properties of Lot TSE-015-019 Virgin and Sample No. 4 at 21 °C, 50 °C, and −20 °C**

Lot CL20/BAMO/AMMO (78%/22%) RDX/BAMO/AMMO (76%/24%)	Stress at Failure (MPa)	Strain at Failure (%)	Modulus (GPa)	Failure Modulus (GPa)	IED (MPa)	FAV
21 °C						
Virgin Material	21.37	7.32	0.310	0.052	5.77	1AB
Sample No. 4	43.17	7.62	0.940	0.102	20.90	3AB
50 °C						
Virgin Material	10.88	8.13	0.119	0.030	2.89	1B
Sample No. 4	20.18	6.61	0.660	0.012	10.73	2AB
−20 °C						
Virgin Material	72.09	7.49	1.39	−0.155	13.17	5AS
Sample No. 4	112.01	6.40	2.79	−0.635	14.80	8AS

2. Approach and Results

The Thiokol Propulsion-layered propellant lot was received in solid sheet form and was without perforations. The lot was cut into samples and stacked, resulting in test specimens with a length-to-diameter (L/D) ratio of 0.96. Sample preparation was accomplished using a 12.68-mm stainless steel hole punch. Sample ends were machined so that the surfaces were flat, parallel to each other, and perpendicular to the extruded axis.

The Material Test Systems (MTS) servohydraulic tester (SHT) mechanical properties tests [1–7] were conducted on several specimens under each test condition. Strain rates of 141.5 (1/s) were achieved. The specimens were taken to failure at ambient pressure to ~60% end strain while conditioned at 21 °C, 50 °C, and −20 °C. The stress at failure, strain at failure, modulus, failure modulus, incremental energy density (IED), and fracture assessment value (FAV) were recorded for each test. The stress vs. strain plots are shown in Figures 2–4, and average values achieved are listed in Table 2.

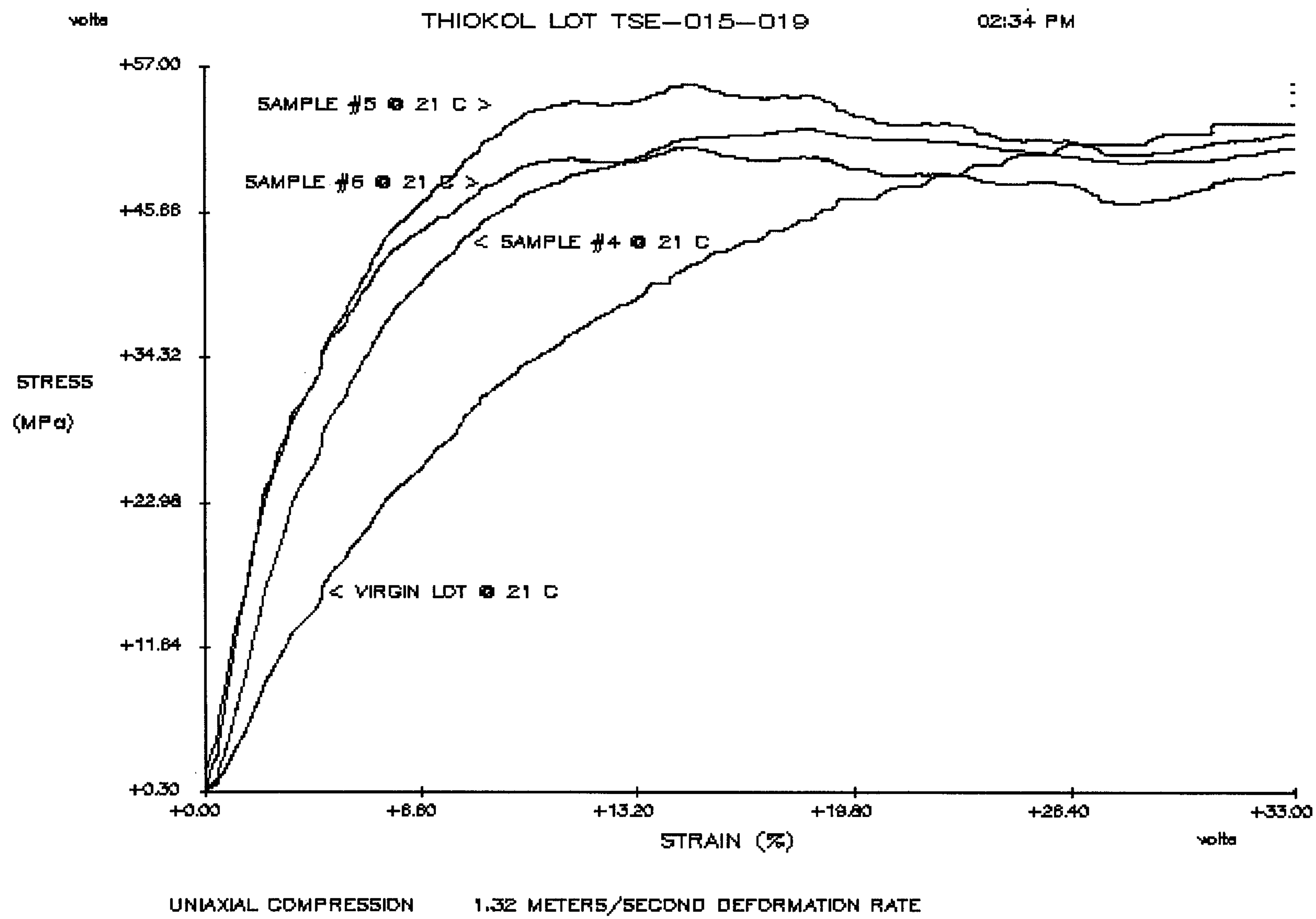

Figure 2. Stress vs. Strain Plot a 21 °C.

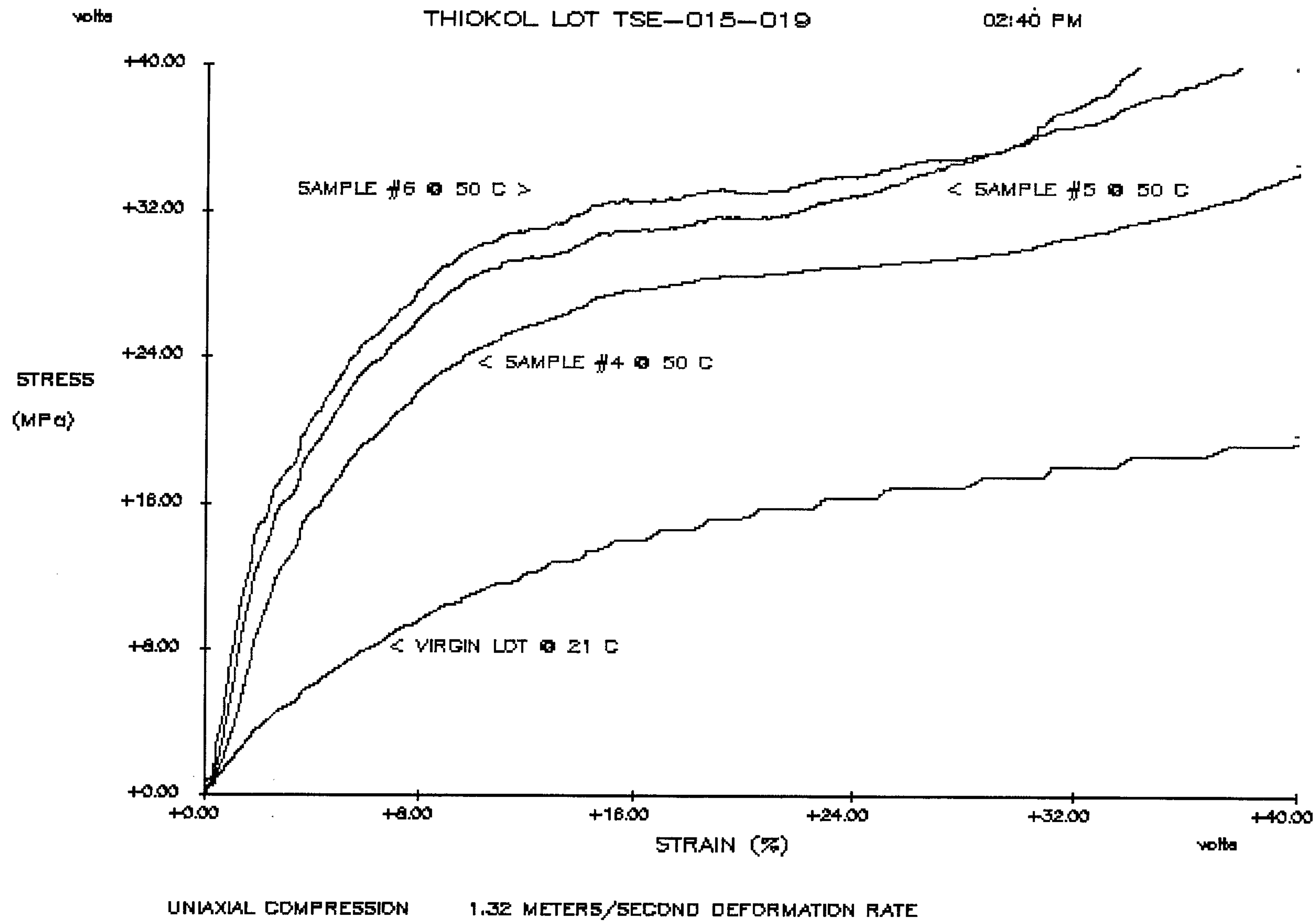

Figure 3. Stress vs. Strain Plot at 50 °C.

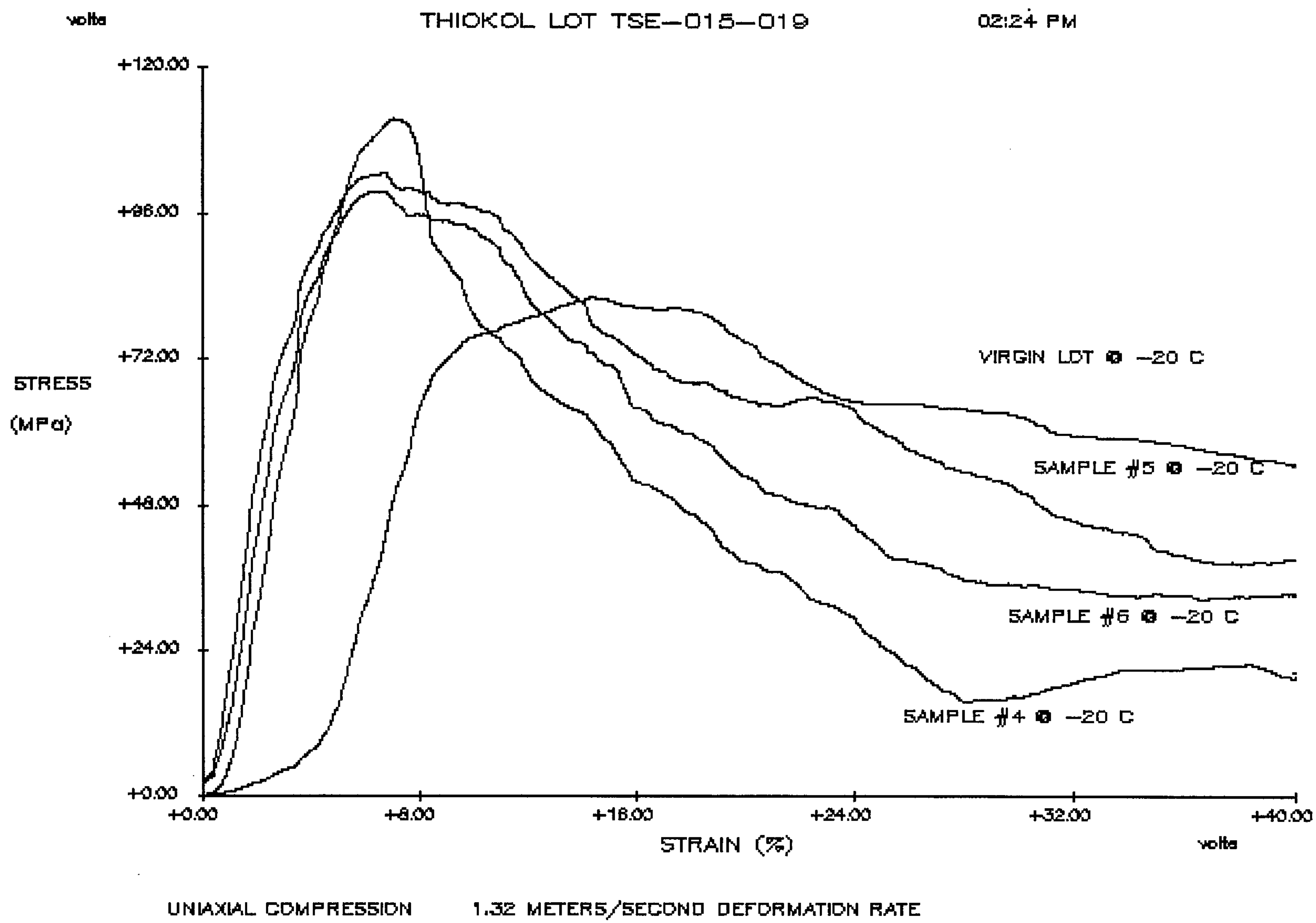

Figure 4. Stress vs. Strain Plot at −20 °C.

Table 2. **Mechanical Properties of Lot TSE-015-019 Sample Nos. 5 and 6 at 21 °C, 50 °C, and −20 °C**

Lot CL20/BAMO/AMMO (78%/22%) RDX/BAMO/AMMO (76%/24%)	Stress at Failure (MPa)	Strain at Failure (%)	Modulus (GPa)	Failure Modulus[a] (GPa)	IED[b] (MPa)	FAV[c]
21 °C						
Sample No. 5	46.09	6.52	1.17	0.089	12.10	3A
Sample No. 6	38.56	5.72	1.00	0.101	11.20	3A
50 °C						
Sample No. 5	21.02	5.21	0.670	0.069	6.26	2AB
Sample No. 6	20.07	5.11	0.640	0.076	6.53	2AB
−20 °C						
Sample No. 5	100.81	6.80	2.69	−0.255	11.10	8AS
Sample No. 6	95.77	6.60	2.23	−0.185	17.80	8AS

[a] The failure modulus (slope of the curve after failure) has been added. Generally, the lower the value, the worse the material (negative value indicates that the material is unable to sustain load). A positive value indicates a positive failure slope (material is better able to support load).
[b] The IED value reported is the amount of energy absorbed at 25% strain; this includes a portion of the area located under the stress/strain curve.
[c] The tested specimens were assigned an FAV. The values range from 0 (no fractures) through 9 (severe fracturing). The type of fracture was also characterized using the following methodology: A = axial fracture, S = shear fracture, B = barreling/deformation, and R = radial splitting (i.e., 8AS would indicate the tested specimens suffered severe axial and shear fracture).

3. Conclusions

Two lots of TSE-015-019 sample nos. 5 and 6 RDX/CL20/BAMO/AMMO-layered gun propellant that was aged for more than 2 years were tested in uniaxial compression at 1.32 m/s. The materials were taken to ~60% end strain while conditioned at 21 °C, 50 °C, and −20 °C. The Thiokol Propulsion-manufactured materials identified by lot TSE-015-019 were also initially tested as virgin material during September 1997 and aged material in January 2000. The test results are included in Table 1.

At 21 °C, it was noted the Young's compressive modulus increased by a factor of more than 3 when compared with the virgin test results contained in Table 1. Note also the increase in compressive modulus when comparing sample nos. 5 and 6 and the aged material sample no. 4 in Table 1. This indicated that the materials may continue to stiffen with aging. The stress at yield also showed a factor of 2 increase when comparing the subject and virgin values. These observations indicated that the material had become much stiffer after being aged for several years. The tested specimens at 21 °C showed permanent deformation of the specimens, with axial fracture also present.

At 50 °C, when comparing the modulus of the aged sample nos. 4, 5, and 6 vs. the virgin material, a factor of more than 5 increase was noted. The stress at failure value also doubled. The tested specimens at 50 °C again showed axial fracture and permanent deformation. This is typical for most gun propellants, as fracture does not usually occur when testing other types of propellants (i.e., M30 and JA2) at 50 °C. This may be cause for concern, as the fractured material would increase the amount of surface area, thus resulting in an increased burn rate of the material.

At −20 °C, the tested specimens from samples nos. 5 and 6 suffered severe amounts of axial and shear fracture (Figure 5), likely causing significant increases in surface area. Note that the tested specimens from the virgin lot (Figure 6) at −20 °C showed less fracture. This indicated that the aged material had become more brittle. The stress vs. strain plot at −20 °C (included in this report) for the materials also correlated with the physical damage observed. The failure modulus values achieved indicated the inability of sample nos. 5 and 6 to sustain load. The uniaxial compression tests at −20 °C, plus the several years of aging, likely caused the material to suffer a glassy transition. It should also be noted that the strain at failure values for sample no. 5, and especially the virgin lot at −20 °C (see stress vs. strain plot at −20 °C), were a bit higher than actual due to material stacking of the test specimens while being conditioned. This could be averted with future tests by testing solid right-circular cylinder specimens instead of stacking the punched sheet material and thus creating air gaps between the layers.

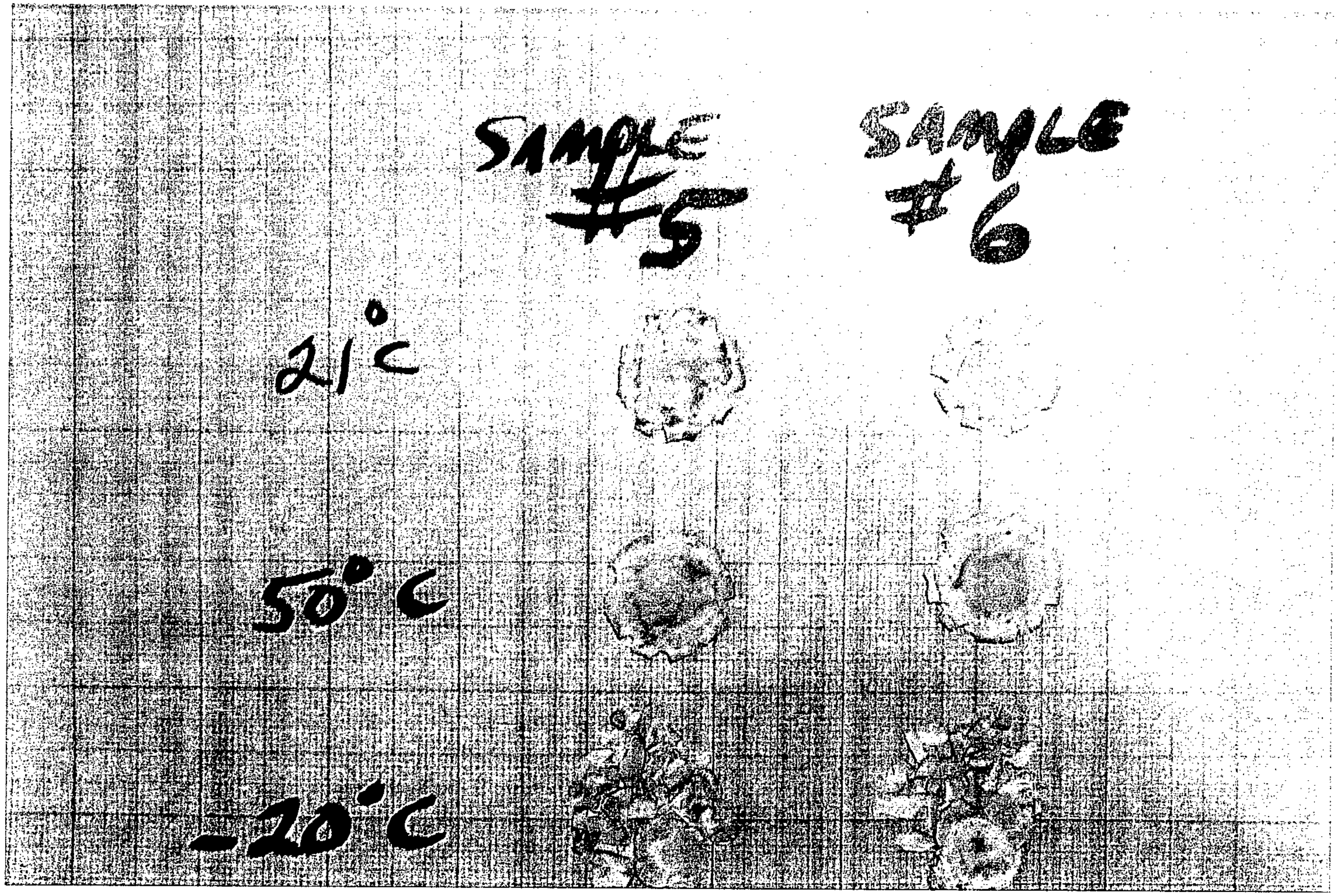

Figure 5. Photograph of Aged Sample Nos. 5 and 6 From Lot TSE-015-019 Tested Material.

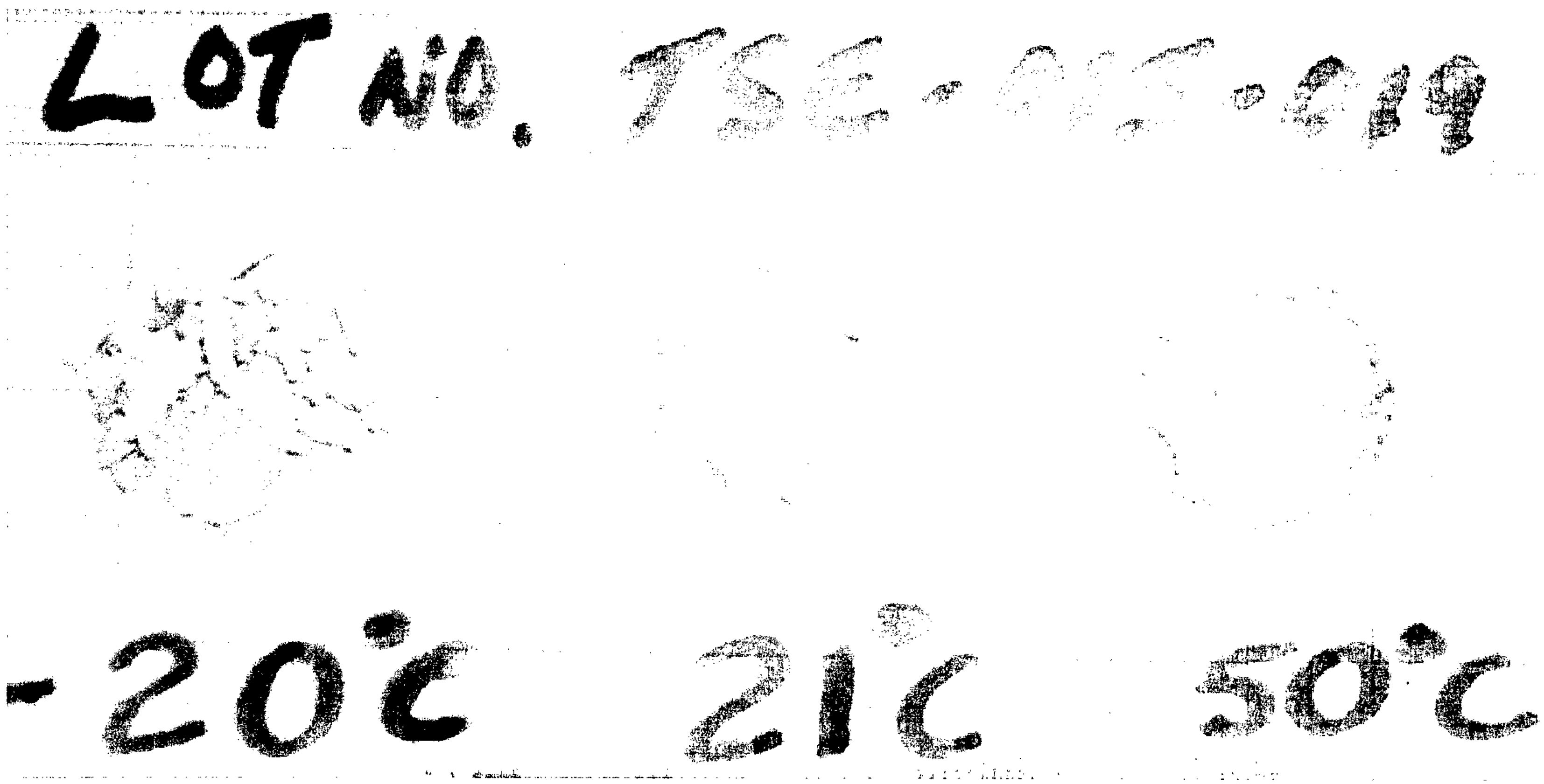

Figure 6. Photograph of Tested Material From Virgin Lot TSE-015-019.

Overall, lot TSE-015-019 showed poor mechanical properties when the virgin lot was initially tested several years ago, and the aging of the material (sample nos. 4, 5, and 6) has proven more detrimental. The −20 °C tests are cause for concern, as the test results indicated the lot was sensitive to the colder testing temperature, becoming "brittle" at −20 °C, and suffering prolific fracture.

4. References

1. Gazonas, G. A. "The Mechanical Response of M30, XM39, and JA2 Propellants at Strain Rates From 10-2 to 250 Sec-1." BRL-TR-3181, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1991.

2. Lieb, R. J. "Impact-Generated Surface Area in Gun Propellant." BRL-TR-2946, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, November 1988.

3. Lieb, R. J., and J. J. Rocchio. "High Strain Rate Mechanical Properties Testing on Lots of Solid Gun Propellant With Deviant Interior Ballistic Performance." *1982 JANNAF Structures and Mechanical Behavior Subcommittee Meeting*, CPIA Publication 368, pp. 23–38, October 1982.

4. Leadore, M. G. "MTS Servo-Hydraulic Tester (SHT) Mechanical Properties Evaluation of M43 Propellants." ARL-TN-5, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, March 1993.

5. Leadore, M. G., and C. J. Gillich. "Material Testing System (MTS) Servo-Hydraulic Tester (SHT) Mechanical Response of Energetic Thermal Plastic Elastomer (ETPE) RDX-Based Propellants." ARL-TN-28, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, April 1994.

6. Leadore, M. G. "Mechanical Response of Energetic Thermoplastic Elastomer Low-Vulnerability Ammunition (ETPE-LOVA) RDX-Based, TNAZ-Based, and CL-20-Based Gun Propellants." ARL-TN-64, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, March 1996.

7. Lieb, R. J. Personal communication. U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, September 2000.

INTENTIONALLY LEFT BLANK.

NO. OF COPIES	ORGANIZATION
2	DEFENSE TECHNICAL INFORMATION CENTER DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218
1	HQDA DAMO FDT 400 ARMY PENTAGON WASHINGTON DC 20310-0460
1	OSD OUSD(A&T)/ODDR&E(R) DR R J TREW 3800 DEFENSE PENTAGON WASHINGTON DC 20301-3800
1	COMMANDING GENERAL US ARMY MATERIEL CMD AMCRDA TF 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	INST FOR ADVNCD TCHNLGY THE UNIV OF TEXAS AT AUSTIN 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
1	US MILITARY ACADEMY MATH SCI CTR EXCELLENCE MADN MATH THAYER HALL WEST POINT NY 10996-1786
1	DIRECTOR US ARMY RESEARCH LAB AMSRL D DR D SMITH 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CI AI R 2800 POWDER MILL RD ADELPHI MD 20783-1197

NO. OF COPIES	ORGANIZATION
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI LL 2800 POWDER MILL RD ADELPHI MD 20783-1197
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI IS T 2800 POWDER MILL RD ADELPHI MD 20783-1197
	ABERDEEN PROVING GROUND
2	DIR USARL AMSRL CI LP (BLDG 305)

NO. OF COPIES	ORGANIZATION
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CP CA D SNIDER 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CI IS R 2800 POWDER MILL RD ADELPHI MD 20783-1145
3	DIRECTOR US ARMY RESEARCH LAB AMSRL OP SD TL 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	DPTY ASST SECY FOR R&T SARD TT THE PENTAGON RM 3EA79 WASHINGTON DC 20301-7100
1	COMMANDER US ARMY MATERIEL CMD AMXMI INT 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
4	COMMANDER US ARMY ARDEC AMSTA AR CC G PAYNE J GEHBAUER C BAULIEU H OPAT PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA ASF PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
2	COMMANDER US ARMY ARDEC AMSTA AR AE WW E BAKER J PEARSON PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR TD C SPINELLI PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR FSE PICATINNY ARSENAL NJ 07806-5000
6	COMMANDER US ARMY ARDEC AMSTA AR CCH A W ANDREWS S MUSALLI R CARR M LUCIANO E LOGSDEN T LOUZEIRO PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR CCH P J LUTZ PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR FSF T C LIVECCHIA PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY ARDEC AMSTA AR QAC T C C PATEL PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR M D DEMELLA PICATINNY ARSENAL NJ 07806-5000
3	COMMANDER US ARMY ARDEC AMSTA AR FSA A WARNASH B MACHAK M CHIEFA PICATINNY ARSENAL NJ 07806-5000
2	COMMANDER US ARMY ARDEC AMSTA AR FSP G M SCHIKSNIS D CARLUCCI PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR FSP A P KISATSKY PICATINNY ARSENAL NJ 07806-5000
2	COMMANDER US ARMY ARDEC AMSTA AR CCH C H CHANIN S CHICO PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR QAC T D RIGOGLIOSO PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY ARDEC AMSTA AR WET T SACHAR BLDG 172 PICATINNY ARSENAL NJ 07806-5000
9	COMMANDER US ARMY ARDEC AMSTA AR CCH B P DONADIA F DONLON P VALENTI C KNUTSON G EUSTICE S PATEL G WAGNECZ R SAYER F CHANG PICATINNY ARSENAL NJ 07806-5000
6	COMMANDER US ARMY ARDEC AMSTA AR CCL F PUZYCKI R MCHUGH D CONWAY E JAROSZEWSKI R SCHLENNER M CLUNE PICATINNY ARSENAL NJ 07806-5000
5	PM SADARM SFAE GCSS SD COL B ELLIS M DEVINE W DEMASSI J PRITCHARD S HROWNAK PICATINNY ARSENAL NJ 07806-5000
1	US ARMY ARDEC INTELLIGENCE SPECIALIST AMSTA AR WEL F M GUERRIERE PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
2	PEO FIELD ARTILLERY SYS SFAE FAS PM H GOLDMAN T MCWILLIAMS PICATINNY ARSENAL NJ 07806-5000
12	PM TMAS SFAE GSSC TMA R MORRIS C KIMKER D GUZIEWICZ E KOPACZ R ROESER R DARCY R KOWALSKI R MCDANOLDS L D ULISSE C ROLLER J MCGREEN B PATTER PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR WEA J BRESCIA PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC PRODUCTION BASE MODERN ACTY AMSMC PBM K PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY TACOM PM ABRAMS SFAE ASM AB 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM AMSTA SF WARREN MI 48397-5000

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY TACOM PM BFVS SFAE GCSS W BV 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	DIRECTOR AIR FORCE RESEARCH LAB MLLMD D MIRACLE 2230 TENTH ST WRIGHT PATTERSON AFB OH 45433-7817
1	OFC OF NAVAL RESEARCH J CHRISTODOULOU ONR CODE 332 800 N QUINCY ST ARLINGTON VA 22217-5600
1	US ARMY CERL R LAMPO 2902 NEWMARK DR CHAMPAIGN IL 61822
1	COMMANDER US ARMY TACOM PM SURVIVABLE SYSTEMS SFAE GCSS W GSI H M RYZYI 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM CHIEF ABRAMS TESTING SFAE GCSS W AB QT T KRASKIEWICZ 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER WATERVLIET ARSENAL SMCWV QAE Q B VANINA BLDG 44 WATERVLIET NY 12189-4050

NO. OF COPIES	ORGANIZATION
3	ARMOR SCHOOL ATZK TD R BAUEN J BERG A POMEY FT KNOX KY 40121
14	COMMANDER US ARMY TACOM AMSTA TR R R MCCLELLAND D THOMAS J BENNETT D HANSEN AMSTA JSK S GOODMAN J FLORENCE K IYER D TEMPLETON A SCHUMACHER AMSTA TR D D OSTBERG L HINOJOSA B RAJU AMSTA CS SF H HUTCHINSON F SCHWARZ WARREN MI 48397-5000
2	HQ IOC TANK AMMUNITION TEAM AMSIO SMT R CRAWFORD W HARRIS ROCK ISLAND IL 61299-6000
14	BENET LABORATORIES AMSTA AR CCB R FISCELLA M SOJA E KATHE M SCAVULO G SPENCER P WHEELER S KRUPSKI J VASILAKIS G FRIAR R HASENBEIN AMSTA CCB R S SOPOK E HYLAND D CRAYON R DILLON WATERVLIET NY 12189-4050

NO. OF COPIES	ORGANIZATION
2	COMMANDER US ARMY AMCOM AVIATION APPLIED TECH DIR J SCHUCK FT EUSTIS VA 23604-5577
1	DIRECTOR US ARMY AMCOM SFAE AV RAM TV D CALDWELL BLDG 5300 REDSTONE ARSENAL AL 35898
2	US ARMY CORPS OF ENGINEERS CERD C T LIU CEW ET T TAN 20 MASS AVE NW WASHINGTON DC 20314
1	US ARMY COLD REGIONS RSCH & ENGRNG LAB P DUTTA 72 LYME RD HANOVER NH 03755
1	USA SBCCOM PM SOLDIER SPT AMSSB PM RSS A J CONNORS KANSAS ST NATICK MA 01760-5057
2	USA SBCCOM MATERIAL SCIENCE TEAM AMSSB RSS J HERBERT M SENNETT KANSAS ST NATICK MA 01760-5057
2	OFC OF NAVAL RESEARCH D SIEGEL CODE 351 J KELLY 800 N QUINCY ST ARLINGTON VA 22217-5660
1	NAVAL SURFACE WARFARE CTR DAHLGREN DIV CODE G06 DAHLGREN VA 22448

NO. OF COPIES	ORGANIZATION
1	NAVAL SURFACE WARFARE CTR TECH LIBRARY CODE 323 17320 DAHLGREN RD DAHLGREN VA 22448
1	NAVAL SURFACE WARFARE CTR CRANE DIVISION M JOHNSON CODE 20H4 LOUISVILLE KY 40214-5245
8	DIRECTOR US ARMY NATIONAL GROUND INTELLIGENCE CTR D LEITER M HOLTUS M WOLFE S MINGLEDORF J GASTON W GSTATTENBAUER R WARNER J CRIDER 220 SEVENTH ST NE CHARLOTTESVILLE VA 22091
2	NAVAL SURFACE WARFARE CTR U SORATHIA C WILLIAMS CD 6551 9500 MACARTHUR BLVD WEST BETHESDA MD 20817
2	COMMANDER NAVAL SURFACE WARFARE CTR CARDEROCK DIVISION R PETERSON CODE 2020 M CRITCHFIELD CODE 1730 BETHESDA MD 20084
8	US ARMY SBCCOM SOLDIER SYSTEMS CENTER BALLISTICS TEAM J WARD W ZUKAS P CUNNIFF J SONG MARINE CORPS TEAM J MACKIEWICZ BUS AREA ADVOCACY TEAM W HASKELL AMSSB RCP SS W NYKVIST S BEAUDOIN KANSAS ST NATICK MA 01760-5019

NO. OF COPIES	ORGANIZATION
9	US ARMY RESEARCH OFC A CROWSON H EVERETT J PRATER G ANDERSON D STEPP D KISEROW J CHANG PO BOX 12211 RESEARCH TRIANGLE PARK NC 27709-2211
8	NAVAL SURFACE WARFARE CTR J FRANCIS CODE G30 D WILSON CODE G32 R D COOPER CODE G32 J FRAYSSE CODE G33 E ROWE CODE G33 T DURAN CODE G33 L DE SIMONE CODE G33 R HUBBARD CODE G33 DAHLGREN VA 22448
1	NAVAL SEA SYSTEMS CMD D LIESE 2531 JEFFERSON DAVIS HWY ARLINGTON VA 22242-5160
1	NAVAL SURFACE WARFARE CTR M LACY CODE B02 17320 DAHLGREN RD DAHLGREN VA 22448
2	NAVAL SURFACE WARFARE CTR CARDEROCK DIVISION R CRANE CODE 2802 C WILLIAMS CODE 6553 3A LEGGETT CIR BETHESDA MD 20054-5000
1	EXPEDITIONARY WARFARE DIV N85 F SHOUP 2000 NAVY PENTAGON WASHINGTON DC 20350-2000
1	AFRL MLBC 2941 P ST RM 136 WRIGHT PATTERSON AFB OH 45433-7750

NO. OF COPIES	ORGANIZATION
1	AFRL MLSS R THOMSON 2179 12TH ST RM 122 WRIGHT PATTERSON AFB OH 45433-7718
2	AFRL F ABRAMS J BROWN BLDG 653 2977 P ST STE 6 WRIGHT PATTERSON AFB OH 45433-7739
1	WATERWAYS EXPERIMENT D SCOTT 3909 HALLS FERRY RD SC C VICKSBURG MS 39180
5	DIRECTOR LLNL R CHRISTENSEN S DETERESA F MAGNESS M FINGER MS 313 M MURPHY L 282 PO BOX 808 LIVERMORE CA 94550
1	AFRL MLS OL L COULTER 7278 4TH ST BLDG 100 BAY D HILL AFB UT 84056-5205
1	OSD JOINT CCD TEST FORCE OSD JCCD R WILLIAMS 3909 HALLS FERRY RD VICKSBURG MS 29180-6199
3	DARPA M VANFOSSEN S WAX L CHRISTODOULOU 3701 N FAIRFAX DR ARLINGTON VA 22203-1714

NO. OF COPIES	ORGANIZATION
2	SERDP PROGRAM OFC PM P2 C PELLERIN B SMITH 901 N STUART ST STE 303 ARLINGTON VA 22203
1	FAA MIL HDBK 17 CHAIR L ILCEWICZ 1601 LIND AVE SW ANM 115N RESTON VA 98055
1	US DEPT OF ENERGY OFC OF ENVIRONMENTAL MANAGEMENT P RITZCOVAN 19901 GERMANTOWN RD GERMANTOWN MD 20874-1928
1	DIRECTOR LOS ALAMOS NATIONAL LAB F L ADDESSIO T 3 MS 5000 PO BOX 1633 LOS ALAMOS NM 87545
1	OAK RIDGE NATIONAL LABORATORY R M DAVIS PO BOX 2008 OAK RIDGE TN 37831-6195
3	DIRECTOR SANDIA NATIONAL LABS APPLIED MECHANICS DEPT MS 9042 J HANDROCK Y R KAN J LAUFFER PO BOX 969 LIVERMORE CA 94551-0969
1	OAK RIDGE NATIONAL LABORATORY C EBERLE MS 8048 PO BOX 2008 OAK RIDGE TN 37831
1	OAK RIDGE NATIONAL LABORATORY C D WARREN MS 8039 PO BOX 2008 OAK RIDGE TN 37831

NO. OF COPIES	ORGANIZATION
5	NIST J DUNKERS M VANLANDINGHAM MS 8621 J CHIN MS 8621 J MARTIN MS 8621 D DUTHINH MS 8611 100 BUREAU DR GAITHERSBURG MD 20899
1	HYDROGEOLOGIC INC SERDP ESTCP SPT OFC S WALSH 1155 HERNDON PKWY STE 900 HERNDON VA 20170
3	NASA LANGLEY RSCH CTR AMSRL VS W ELBER MS 266 F BARTLETT JR MS 266 G FARLEY MS 266 HAMPTON VA 23681-0001
1	NASA LANGLEY RSCH CTR T GATES MS 188E HAMPTON VA 23661-3400
1	FHWA E MUNLEY 6300 GEORGETOWN PIKE MCLEAN VA 22101
3	CYTEC FIBERITE R DUNNE D KOHLI R MAYHEW 1300 REVOLUTION ST HAVRE DE GRACE MD 21078
1	USDOT FEDERAL RAILRD M FATEH RDV 31 WASHINGTON DC 20590
1	MARINE CORPS INTLLGNC ACTVTY D KOSITZKE 3300 RUSSELL RD STE 250 QUANTICO VA 22134-5011
1	DIRECTOR NATIONAL GRND INTLLGNC CTR IANG TMT 220 SEVENTH ST NE CHARLOTTESVILLE VA 22902-5396

NO. OF COPIES	ORGANIZATION
1	SIOUX MFG B KRIEL PO BOX 400 FT TOTTEN ND 58335
2	3TEX CORPORATION A BOGDANOVICH J SINGLETARY 109 MACKENAN DR CARY NC 27511
1	3M CORPORATION J SKILDUM 3M CENTER BLDG 60 IN 01 ST PAUL MN 55144-1000
1	DIRECTOR DEFENSE INTLLGNC AGNCY TA 5 K CRELLING WASHINGTON DC 20310
1	ADVANCED GLASS FIBER YARNS T COLLINS 281 SPRING RUN LANE STE A DOWNINGTON PA 19335
1	COMPOSITE MATERIALS INC D SHORTT 19105 63 AVE NE PO BOX 25 ARLINGTON WA 98223
1	JPS GLASS L CARTER PO BOX 260 SLATER RD SLATER SC 29683
1	COMPOSITE MATERIALS INC R HOLLAND 11 JEWEL CT ORINDA CA 94563
1	COMPOSITE MATERIALS INC C RILEY 14530 S ANSON AVE SANTA FE SPRINGS CA 90670
2	SIMULA J COLTMAN R HUYETT 10016 S 51ST ST PHOENIX AZ 85044

NO. OF COPIES	ORGANIZATION
2	PROTECTION MATERIALS INC M MILLER F CRILLEY 14000 NW 58 CT MIAMI LAKES FL 33014
2	FOSTER MILLER M ROYLANCE W ZUKAS 195 BEAR HILL RD WALTHAM MA 02354-1196
1	ROM DEVELOPMENT CORP R O MEARA 136 SWINEBURNE ROW BRICK MARKET PLACE NEWPORT RI 02840
2	TEXTRON SYSTEMS T FOLTZ M TREASURE 1449 MIDDLESEX ST LOWELL MA 01851
1	O GARA HESS & EISENHARDT M GILLESPIE 9113 LESAINT DR FAIRFIELD OH 45014
2	MILLIKEN RSCH CORP H KUHN M MACLEOD PO BOX 1926 SPARTANBURG SC 29303
1	CONNEAUGHT INDUSTRIES INC J SANTOS PO BOX 1425 COVENTRY RI 02816
1	BATTELLE NATICK OPNS B HALPIN 209 W CENTRAL ST STE 302 NATICK MA 01760
1	ARMTEC DEFENSE PRODUCTS S DYER 85 901 AVE 53 PO BOX 848 COACHELLA CA 92236

NO. OF COPIES	ORGANIZATION
1	NATIONAL COMPOSITE CENTER T CORDELL 2000 COMPOSITE DR KETTERING OH 45420
3	PACIFIC NORTHWEST LAB M SMITH G VAN ARSDALE R SHIPPELL PO BOX 999 RICHLAND WA 99352
2	AMOCO PERFORMANCE PRODUCTS M MICHNO JR J BANISAUKAS 4500 MCGINNIS FERRY RD ALPHARETTA GA 30202-3944
1	SAIC M PALMER 1410 SPRING HILL RD STE 400 MS SH4 5 MCLEAN VA 22102
8	ALLIANT TECHSYSTEMS INC C CANDLAND MN11 2830 C AAKHUS MN11 2830 B SEE MN11 2439 N VLAHAKUS MN11 2145 R DOHRN MN11 2830 S HAGLUND MN11 2439 M HISSONG MN11 2830 D KAMDAR MN11 2830 600 SECOND ST NE HOPKINS MN 55343-8367
1	SAIC G CHRYSSOMALLIS 3800 W 80TH ST STE 1090 BLOOMINGTON MN 55431
1	AAI CORPORATION T G STASTNY PO BOX 126 HUNT VALLEY MD 21030-0126
1	APPLIED COMPOSITES W GRISCH 333 NORTH SIXTH ST ST CHARLES IL 60174

NO. OF COPIES	ORGANIZATION
1	CUSTOM ANALYTICAL ENG SYS INC A ALEXANDER 13000 TENSOR LANE NE FLINTSTONE MD 21530
3	ALLIANT TECHSYSTEMS INC J CONDON E LYNAM J GERHARD WV01 16 STATE RT 956 PO BOX 210 ROCKET CENTER WV 26726-0210
1	OFC DEPUTY UNDER SEC DEFNS J THOMPSON 1745 JEFFERSON DAVIS HWY CRYSTAL SQ 4 STE 501 ARLINGTON VA 22202
1	PROJECTILE TECHNOLOGY INC 515 GILES ST HAVRE DE GRACE MD 21078
5	AEROJET GEN CORP D PILLASCH T COULTER C FLYNN D RUBAREZUL M GREINER 1100 WEST HOLLYVALE ST AZUSA CA 91702-0296
3	HEXCEL INC R BOE PO BOX 18748 SALT LAKE CITY UT 84118
1	HERCULES INC HERCULES PLAZA WILMINGTON DE 19894
1	BRIGS COMPANY J BACKOFEN 2668 PETERBOROUGH ST HERNDON VA 22071-2443
1	ZERNOW TECHNICAL SERVICES L ZERNOW 425 W BONITA AVE STE 208 SAN DIMAS CA 91773

NO. OF COPIES	ORGANIZATION
1	GENERAL DYNAMICS OTS L WHITMORE 10101 NINTH ST NORTH ST PETERSBURG FL 33702
3	GENERAL DYNAMICS OTS FLINCHBAUGH DIV E STEINER B STEWART T LYNCH PO BOX 127 RED LION PA 17356
1	GKN AEROSPACE D OLDS 15 STERLING DR WALLINGFORD CT 06492
1	PRATT & WHITNEY C WATSON 400 MAIN ST MS 114 37 EAST HARTFORD CT 06108
5	SIKORSKY AIRCRAFT G JACARUSO T CARSTENSAN B KAY S GARBO MS S330A J ADELMANN 6900 MAIN ST PO BOX 9729 STRATFORD CT 06497-9729
1	AEROSPACE CORP G HAWKINS M4 945 2350 E EL SEGUNDO BLVD EL SEGUNDO CA 90245
2	CYTEC FIBERITE M LIN W WEB 1440 N KRAEMER BLVD ANAHEIM CA 92806
1	UDLP G THOMAS PO BOX 58123 SANTA CLARA CA 95052
2	UDLP R BARRETT MAIL DROP M53 V HORVATICH MAIL DROP M53 328 W BROKAW RD SANTA CLARA CA 95052-0359

NO. OF COPIES	ORGANIZATION
3	UDLP GROUND SYSTEMS DIVISION M PEDRAZZI MAIL DROP N09 A LEE MAIL DROP N11 M MACLEAN MAIL DROP N06 1205 COLEMAN AVE SANTA CLARA CA 95052
4	UDLP R BRYNSVOLD P JANKE MS 170 4800 EAST RIVER RD MINNEAPOLIS MN 55421-1498
2	BOEING DFNSE & SPACE GP W HAMMOND S 4X55 J RUSSELL S 4X55 PO BOX 3707 SEATTLE WA 98124-2207
2	BOEING ROTORCRAFT P MINGURT P HANDEL 800 B PUTNAM BLVD WALLINGFORD PA 19086
1	BOEING DOUGLAS PRODUCTS DIV L J HART SMITH 3855 LAKEWOOD BLVD D800 0019 LONG BEACH CA 90846-0001
1	LOCKHEED MARTIN SKUNK WORKS D FORTNEY 1011 LOCKHEED WAY PALMDALE CA 93599-2502
1	LOCKHEED MARTIN R FIELDS 1195 IRWIN CT WINTER SPRINGS FL 32708
1	MATERIALS SCIENCES CORP G FLANAGAN 500 OFC CENTER DR STE 250 FT WASHINGTON PA 19034

NO. OF COPIES	ORGANIZATION
1	NORTHRUP GRUMMAN CORP ELECTRONIC SENSORS & SYSTEMS DIV E SCHOCH MS V 16 1745A W NURSERY RD LINTHICUM MD 21090
1	GDLS DIVISION D BARTLE PO BOX 1901 WARREN MI 48090
2	GDLS D REES M PASIK PO BOX 2074 WARREN MI 48090-2074
1	GDLS MUSKEGON OPERATIONS W SOMMERS JR 76 GETTY ST MUSKEGON MI 49442
1	GENERAL DYNAMICS AMPHIBIOUS SYS SURVIVABILITY LEAD G WALKER 991 ANNAPOLIS WAY WOODBRIDGE VA 22191
6	INST FOR ADVANCED TECH H FAIR I MCNAB P SULLIVAN S BLESS W REINECKE C PERSAD 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
2	CIVIL ENGR RSCH FOUNDATION PRESIDENT H BERNSTEIN R BELLE 1015 15TH ST NW STE 600 WASHINGTON DC 20005
1	ARROW TECH ASSO 1233 SHELBURNE RD STE D8 SOUTH BURLINGTON VT 05403-7700

NO. OF COPIES	ORGANIZATION
1	R EICHELBERGER CONSULTANT 409 W CATHERINE ST BEL AIR MD 21014-3613
1	UCLA MANE DEPT ENGR IV H T HAHN LOS ANGELES CA 90024-1597
2	UNIV OF DAYTON RESEARCH INST R Y KIM A K ROY 300 COLLEGE PARK AVE DAYTON OH 45469-0168
1	UMASS LOWELL PLASTICS DEPT N SCHOTT 1 UNIVERSITY AVE LOWELL MA 01854
1	IIT RESEARCH CENTER D ROSE 201 MILL ST ROME NY 13440-6916
1	GA TECH RSCH INST GA INST OF TCHNLGY P FRIEDERICH ATLANTA GA 30392
1	MICHIGAN ST UNIV MSM DEPT R AVERILL 3515 EB EAST LANSING MI 48824-1226
1	UNIV OF WYOMING D ADAMS PO BOX 3295 LARAMIE WY 82071
2	PENN STATE UNIV R MCNITT C BAKIS 212 EARTH ENGR SCIENCES BLDG UNIVERSITY PARK PA 16802
1	PENN STATE UNIV R S ENGEL 245 HAMMOND BLDG UNIVERSITY PARK PA 16801

NO. OF COPIES	ORGANIZATION
1	PURDUE UNIV SCHOOL OF AERO & ASTRO C T SUN W LAFAYETTE IN 47907-1282
1	STANFORD UNIV DEPT OF AERONAUTICS & AEROBALLISTICS S TSAI DURANT BLDG STANFORD CA 94305
1	UNIV OF MAIN ADV STR & COMP LAB R LOPEZ ANIDO 5793 AEWC BLDG ORONO ME 04469-5793
1	JOHNS HOPKINS UNIV APPLIED PHYSICS LAB P WIENHOLD 11100 JOHNS HOPKINS RD LAUREL MD 20723-6099
1	UNIV OF DAYTON J M WHITNEY COLLEGE PARK AVE DAYTON OH 45469-0240
5	UNIV OF DELAWARE CTR FOR COMPOSITE MTRLS J GILLESPIE M SANTARE S YARLAGADDA S ADVANI D HEIDER 201 SPENCER LABORATORY NEWARK DE 19716
1	DEPT OF MATERIALS SCIENCE & ENGINEERING UNIVERSITY OF ILLINOIS AT URBANA CHAMPAIGN J ECONOMY 1304 WEST GREEN ST 115B URBANA IL 61801
1	NORTH CAROLINA STATE UNIV CIVIL ENGINEERING DEPT W RASDORF PO BOX 7908 RALEIGH NC 27696-7908

NO. OF COPIES	ORGANIZATION
1	UNIV OF MARYLAND DEPT OF AEROSPACE ENGNRNG A J VIZZINI COLLEGE PARK MD 20742
3	UNIV OF TEXAS AT AUSTIN CTR FOR ELECTROMECHANICS J PRICE A WALLS J KITZMILLER 10100 BURNET RD AUSTIN TX 78758-4497
3	VA POLYTECHNICAL INST & STATE UNIV DEPT OF ESM M W HYER K REIFSNIDER R JONES BLACKSBURG VA 24061-0219
1	DREXEL UNIV A S D WANG 32ND & CHESTNUT ST PHILADELPHIA PA 19104
1	SOUTHWEST RSCH INST ENGR & MATL SCIENCES DIV J RIEGEL 6220 CULEBRA RD PO DRAWER 28510 SAN ANTONIO TX 78228-0510
	ABERDEEN PROVING GROUND
1	US ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY P DIETZ 392 HOPKINS RD AMXSY TD APG MD 21005-5071
1	DIRECTOR US ARMY RESEARCH LAB AMSRL OP AP L APG MD 21005-5066
90	DIR USARL AMSRL CI AMSRL CI S A MARK

NO. OF COPIES	ORGANIZATION
	AMSRL CS IO FI M ADAMSON AMSRL SL BA AMSRL SL BL D BELY R HENRY AMSRL SL BG AMSRL SL I AMSRL WM J SMITH AMSRL WM B A HORST AMSRL WM BA D LYON AMSRL WM BC P PLOSTINS J NEWILL S WILKERSON A ZIELINSKI AMSRL WM BD B FORCH R FIFER R PESCE RODRIGUEZ B RICE AMSRL WM BE C LEVERITT AMSRL WM BF J LACETERA AMSRL WM BR C SHOEMAKER J BORNSTEIN AMSRL WM M D VIECHNICKI G HAGNAUER J MCCAULEY AMSRL WM MA L GHIORSE S MCKNIGHT AMSRL WM MB B FINK J BENDER T BOGETTI R BOSSOLI L BURTON K BOYD S CORNELISON P DEHMER R DOOLEY W DRYSDALE G GAZONAS S GHIORSE D GRANVILLE D HOPKINS C HOPPEL

NO. OF COPIES	ORGANIZATION
	ABERDEEN PROVING GROUND (CONT)
	D HENRY R KASTE M KLUSEWITZ M LEADORE R LIEB E RIGAS J SANDS D SPAGNUOLO W SPURGEON J TZENG E WETZEL A FRYDMAN AMRSL WM MC J BEATTY E CHIN J MONTGOMERY A WERECZCAK J LASALVIA J WELLS AMSRL WM MD W ROY S WALSH AMSRL WM T B BURNS M ZOLTOSKI AMSRL WM TA W GILLICH T HAVEL J RUNYEON M BURKINS E HORWATH B GOOCH W BRUCHEY M NORMANDIA AMRSL WM TB D KOOKER P BAKER AMSRL WM TC R COATES AMSRL WM TD A DAS GUPTA T HADUCH T MOYNIHAN F GREGORY M RAFTENBERG M BOTELER T WEERASOORIYA D DANDEKAR A DIETRICH AMSRL WM TE A NIILER J POWELL

NO. OF COPIES	ORGANIZATION
	ABERDEEN PROVING GROUND (CONT)
	AMSRL SS SD H WALLACE AMSRL SS SE DS R REYZER R ATKINSON

NO. OF COPIES	ORGANIZATION
1	LTD R MARTIN MERL TAMWORTH RD HERTFORD SG13 7DG UK
1	SMC SCOTLAND P W LAY DERA ROSYTH ROSYTH ROYAL DOCKYARD DUNFERMLINE FIFE KY 11 2XR UK
1	CIVIL AVIATION ADMINSTRATION T GOTTESMAN PO BOX 8 BEN GURION INTERNL AIRPORT LOD 70150 ISRAEL
1	AEROSPATIALE S ANDRE A BTE CC RTE MD132 316 ROUTE DE BAYONNE TOULOUSE 31060 FRANCE
1	DRA FORT HALSTEAD P N JONES SEVEN OAKS KENT TN 147BP UK
1	DEFENSE RESEARCH ESTAB VALCARTIER F LESAGE COURCELETTE QUEBEC COA IRO CANADA
1	SWISS FEDERAL ARMAMENTS WKS W LANZ ALLMENDSTRASSE 86 3602 THUN SWITZERLAND
1	DYNAMEC RESEARCH AB AKE PERSSON BOX 201 SE 151 23 SODERTALJE SWEDEN

NO. OF COPIES	ORGANIZATION
1	ISRAEL INST OF TECHNOLOGY S BODNER FACULTY OF MECHANICAL ENGR HAIFA 3200 ISRAEL
1	DSTO AMRL WEAPONS SYSTEMS DIVISION N BURMAN RLLWS SALISBURY SOUTH AUSTRALIA 5108 AUSTRALIA
1	ECOLE ROYAL MILITAIRE E CELENS AVE DE LA RENAISSANCE 30 1040 BRUXELLE BELGIQUE
1	DEF RES ESTABLISHMENT VALCARTIER A DUPUIS 2459 BOULEVARD PIE XI NORTH VALCARTIER QUEBEC CANADA PO BOX 8800 COURCELETTE GOA IRO QUEBEC CANADA
1	INSTITUT FRANCO ALLEMAND DE RECHERCHES DE SAINT LOUIS DE M GIRAUD 5 RUE DU GENERAL CASSAGNOU BOITE POSTALE 34 F 68301 SAINT LOUIS CEDEX FRANCE
1	ECOLE POLYTECH J MANSON DMX LTC CH 1015 LAUSANNE SWITZERLAND

NO. OF COPIES	ORGANIZATION
1	TNO PRINS MAURITS LABORATORY R IJSSELSTEIN LANGE KLEIWEG 137 PO BOX 45 2280 AA RIJSWIJK THE NETHERLANDS
2	FOA NATL DEFENSE RESEARCH ESTAB DIR DEPT OF WEAPONS & PROTECTION B JANZON R HOLMLIN S 172 90 STOCKHOLM SWEDEN
2	DEFENSE TECH & PROC AGENCY GROUND I CREWTHER GENERAL HERZOG HAUS 3602 THUN SWITZERLAND
1	MINISTRY OF DEFENCE RAFAEL ARMAMENT DEVELOPMENT AUTH M MAYSELESS PO BOX 2250 HAIFA 31021 ISRAEL
1	TNO DEFENSE RESEARCH I H PASMAN POSTBUS 6006 2600 JA DELFT THE NETHERLANDS
1	B HIRSCH TACHKEMONY ST 6 NETAMUA 42611 ISRAEL
1	DEUTSCHE AEROSPACE AG DYNAMICS SYSTEMS M HELD PO BOX 1340 D 86523 SCHROBENHAUSEN GERMANY

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2001	Final, March 2000–October 2000

4. TITLE AND SUBTITLE
The Mechanical Response of Virgin and Aged RDX/CL20/BAMO/AMMO-Based High-Energy Gun Propellants

5. FUNDING NUMBERS
1L161102AH43

6. AUTHOR(S)
Michael G. Leadore

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-WM-MB
Aberdeen Proving Ground, MD 21005-5069

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-2603

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

10.SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT*(Maximum 200 words)*

The subject of this report is the material test systems servohydraulic tester high-rate mechanical response of TSE-015-019 sample nos. 5 and 6 RDX/CL20/BAMO/AMMO-layered gun propellants that were aged for more than 2 years. The Thiokol manufactured materials identified by lot TSE-015-019 were initially tested (virgin lot) in September 1997 and January 2000. Sample no. 4 was a candidate propellant for the M829E3 120-mm tank gun round of test sets 28–34/FY00.

14. SUBJECT TERMS
CL20, RDX, BAMO/AMMO, uniaxial compression, high strain rate, stress, strain, mechanical properties, modulus, failure modulus, incremental energy density, fracture, deformation, high energy

15. NUMBER OF PAGES
32

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

INTENTIONALLY LEFT BLANK.